Report 14354-M-7

HYDROGEN-OXYGEN HIGH P_c APS ENGINES

NAS 3-14354

Period Ending 25 April 1971

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Prepared for
NASA-Lewis Research Center
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AEROJET LIQUID ROCKET COMPANY
SACRAMENTO, CALIFORNIA • A DIVISION OF AEROJET-GENERAL

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FOREWORD

This is the seventh monthly report for Contract NAS 3-14354. The purpose of this contract is the development of a comprehensive technology base for high performance, long life, gaseous hydrogen - gaseous oxygen rocket engines suitable for the Space Shuttle APS. Significant goals in thruster design are a 50-hour firing life over a 10-year period, with up to 10^6 restarts, and single firings up to 1000 sec.

The program was initially structured as two parallel efforts: one directed toward high pressure (100 to 500 psia) systems and the other toward low pressure (10 to 20 psia) systems. Nominal engine thrust in each case is 1500 lb. Initial program tasks were devoted to the analytical evaluation and screening of injector and cooled thrust chamber concepts for both pressure levels. This was followed by closely paralleled but separate experimental evaluations of low and high pressure injectors and ignition devices. Recommendations of specific injector and igniter designs have been made for both pressure levels as a result of these tests

As these parallel efforts were about to enter the cooled chamber fabrication phase, the program was redirected to apply additional emphasis on the high P_c technology with a revised schedule on propellant inlet temperatures. Activities on the low pressure phase were terminated by a stop work order, which eliminated the requirements for a portion of the injector testing and all of the low P_c cooled chamber fabrication, durability and pulse testing. The program's resources originally planned for these activities have been reallocated to expand design and test efforts related to the lower temperature gaseous propellants.

Mr. L. Schoenman, project manager for the high pressure phase, reports to Dr. R. J. LaBotz, who is program manager of all ALRC APS thruster programs. The NASA Lewis Research Center program manager is Mr. J. Gregory.

I. PROGRAM OBJECTIVES

The primary objective of this contract is to generate a comprehensive technology base for high performance gaseous hydrogen-gaseous oxygen rocket engines suitable for the Space Shuttle Auxiliary Propulsion System (APS). Durability requirements include injector and thrust chamber designs capable of 50 hours of firing life over a 10-year period with up to 10^6 pulses and single firings up to 1000 sec. These technical objectives are being accomplished and reported upon in a 28-task program summarized below. The first 10 tasks relate to high pressure APS engines, parallel tasks XI through XX relate to low pressure APS engines, and task XXI is a common reporting task. The additional tasks are for the expanded High P_c Low Temperature Program.

Task Titles	High P_c Task		Low P_c Task
	Amb. Prop.	Low Temp Prop.	
Injector analysis and design	I*	XXII	XI*
Injector fabrication	II*	XXIII	XII*
Thrust chamber analysis and design	III*	XXIV	XIII*
Thrust chamber fabrication	IV	XXV	XIV*
Ignition system analysis and design	V*	--	XV*
Ignition system fabrication and checkout	VI*	--	XVI*
Propellant valves preparation	VII*	--	XVII*
Injector tests	VIII*	XXVI	XVIII*
Thrust chamber cooling tests	IX	XXVII	XIX*
Pulsing tests	X	XXVIII	XX*

Common Task

Reporting requirements XXI

*Completed tasks for revised program.

II. PROGRAM PROGRESS

A. AMBIENT TEMPERATURE PROPELLANT TASKS

1. Task I - Injector Analysis and Design

No Activity

2. Task II - Injector Fabrication

Two injectors of the premix impinging type and three film cooling rings were modified for use with 40:1 cooled chamber designs as follows:

I Premix Triplet	SN-5
Premix Triplet	SN-3
20% - 1" long film cooling ring	
20% - 0 length film cooling ring	
10% - 0 length film cooling ring	

3. Task III - Cooled Chamber Analysis and Design

Evaluation of heat flux and film cooling data from Task VIII testing was completed. The structural analysis was reviewed in order to select optimum locations for strain gage instrumentation and also to reassess the life potential of the chamber being fabricated based on Task VIII test data.

4. Task IV - Thrust Chamber Fabrication

a. Film Cooled Chamber Design

Fabrication of the first film cooled chamber assembly was completed. The chamber was cold flowed, leak and pressure checked. Flow distribution in film cooling channels and regen section were acceptable; there

II, A, 4, a, Film Cooled Chamber Design (cont.)

were no leaks. The chamber was then instrumented and insulated with a 1/2" thick blanket of aluminum-backed LoCon* insulation.

The weight of the final assembly including insulation was 19 lbs. It appears possible to reduce the weight of this design by at least 6 additional pounds for the final flight configuration.

Instrumentation consisted of 36 wall temperature measurements, as shown in Figure III-32 of Ref. 1, two coolant temperature sensing probes and six channels of external case strain measurements. Figure 1 shows the SN-1 film cooled chamber during instrumentation and after application of the skirt insulation blanket (lower right). Final assembly of the second film cooled chamber containing the Zirconium copper liner was initiated following successful bonding and cold flow checkout of the manifolding in the first assembly.

b. Regeneratively Cooled Chamber Design

Two slotted copper regeneratively cooled chambers were processed to the point where slotting of the coolant channels were completed. The coolant channels on this design are of stepped construction. The initial channel was cut with a .060 in. wide cutter and .060 in. constant depth. A second variable depth .050 in. wide contour cut formed the coolant channels of variable cross-sectional flow. Channel closeout was accomplished by brazing precontoured .060 in. square copper wires into the slots. The .005 in. ledge formed by the stepped machining provides a positive channel depth control. Channel closeouts using the square wires were accomplished on both OFHC and Zirconium copper chambers. The forward flange and aft manifold for the OFHC copper body were applied in a second brazing operation. Chamber fabrication

* Commercial product - by Carborundum Co.

Ref. 1 L. Schoenman and A. A. Oare, "Hydrogen-Oxygen High P_c APS Engines", Report 14354-Q-3, 14 April 1971

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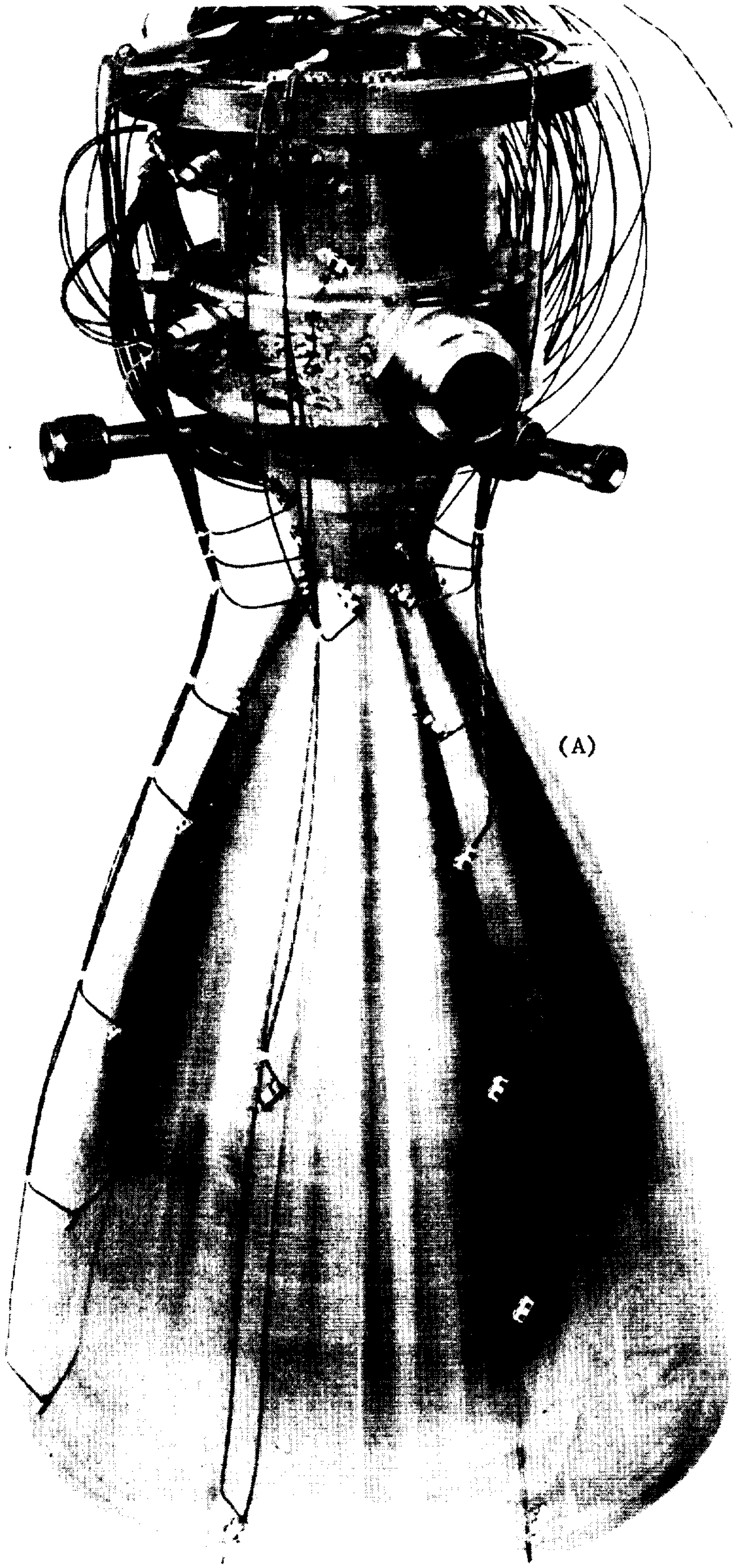
Figure 1 -- Film Cooled Thrust Chamber

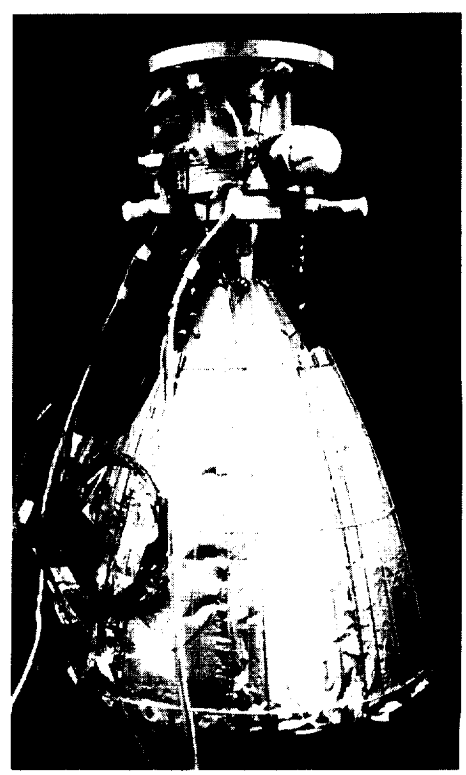
(C)

X Gas-Side & Back-Side Temperature Measurement

(A)



(B)



(A) Instrumentation in process
(B) Instrumentation & Skirt Insulation complete
(C) Thermocouple & Strain Patch detail

II, A, 4, b, Regeneratively Cooled Chamber Design (cont.)

up to this stage is shown in Figure 2. Fifteen .020 dia. chromel alumel thermocouples were installed through .0225 dia. holes drilled through the ribs, positioned flush with the gas-side surface. These are bonded in a third brazing cycle.

The final fabrication operation on this design will be to electroform a thin .050 in. nickel case over the copper body. This additional operation provides the structural support which will allow operation at chamber pressures of 500 psia.

The electroform operation is scheduled to take one week. The second chamber case will be electroformed following the successful completion of the first unit.

A subassembly for this design is the film cooled skirt which bolts to the inlet manifold of the regeneratively cooled chamber section. This subassembly is also shown in Figure 2. Two film cooled skirts have been completed to the point where they can be bolted to the chamber section. Final operation on this assembly will be to blend the interface to remove all steps.

5. <u>Task V - Igniter Design and Analysis</u>

No activity

6. <u>Task VI - Igniter Checkout Tests</u>

No activity

7. <u>Task VII - Valve Preparation</u>

No activity

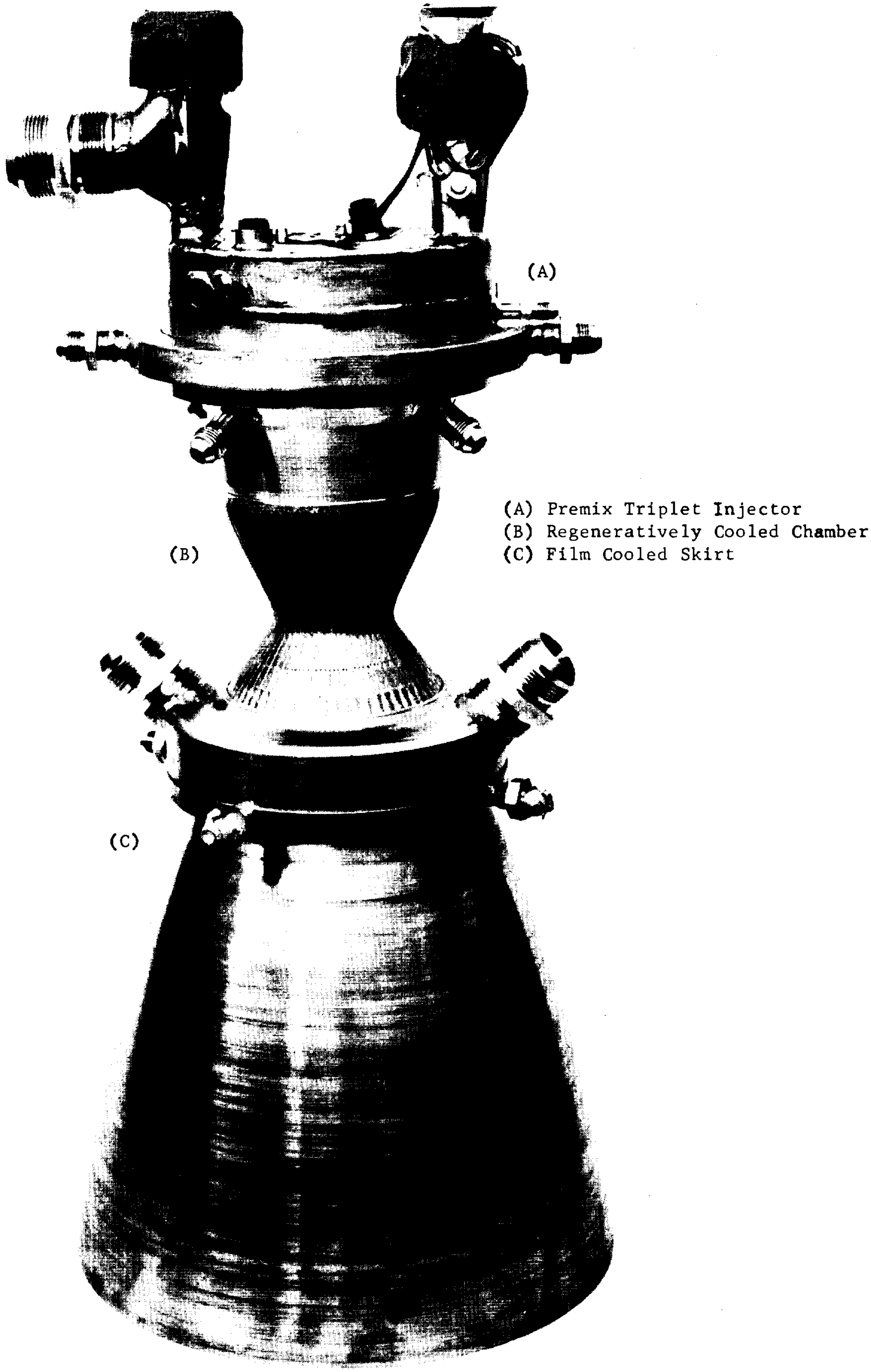


Figure 2 -- Regeneratively Cooled Thrust Chamber

8. Task VIII - Injector Checkout Tests

No activity

9. Task IX - Cooled Chamber Testing

The rocket engine firing fixture used in the Research Physics Lab for Task VIII sea level injector checkout tests has been moved into the J-3 Altitude Test Facility and activated. The firing fixture, designed and built to accommodate this transfer, allowed transport of all valves, flow measuring lines, flow control nozzles and thrust take-out structure as a single assembly.

Altitude testing is scheduled to start in the next report period. A series of checkout tests of new facility Heat Exchangers to be employed for testing with hot or cold propellants was conducted on the Fuel Heat Exchanger using LN_2 to cool gaseous hydrogen. The targeted fuel discharge temperature of 200^oR could not be attained at design flow rates. Additional heat exchanger coils, consisting of finned tubing, and a new containment vessel have been supplied by the heat exchanger manufacturer and these are currently being installed in the J-3 Test Facility. Additional cooling capacity is also being added to the Oxidizer Heat Exchanger.

10. Task X - Pulse Testing

No activity

11. Task XXI - Reporting

The third Quarterly Report was distributed per the NASA distribution list. A test plan, which describes Task IX test conditions, instrumentation, data parameters, and format of data presentation, was prepared and submitted for the approval of the NASA program manager.

II,A,4,b,11, Task XXI Reporting (cont.)

Reporting on the Low P_c Program, Tasks XI through XXI, was limited to preparing a draft copy of the final report. The following additional activities on this task were related to program redirection.

A revised program plan, schedule and the requested cost to complete of (1) the unmodified High-Low Program, and (2) redirected High P_c Program combination was prepared.

B. HIGH P_c TASKS IN REDIRECTED PROGRAM

1. Task XXII - Design of Injector for Low Temperature Propellants

Design of a new injector manifold suitable for pulsing with low temperature propellants was initiated. This new manifold configuration incorporates the most successful features of both high and low P_c injector designs as established from the extensive manifold cold flow studies which were conducted in the earlier tasks. The new manifolding is being designed to accommodate a bonded platelet stack containing 72 injector elements. The final pattern to be applied can be either the "I" premix triplet, a premix triplet, or any other improved pattern which can be generated by the bonded plate stack design approach. Design activities now in progress include manifold design and drafting, and structural analyses.

III. PROBLEM AREAS

There are no major problems at this time. The inability of the facility heat exchanger to provide the desired low propellant temperatures is expected to delay completion of Task XI by two to three weeks.

IV. WORK DURING NEXT REPORTING PERIOD

Tasks I through VIII - no activity.

Task IX - Initiate cooled chamber testing and evaluate test data. Install and check out new facility heat exchangers.

Task X - Finalize Test Plan, flow control and flow measuring procedures.

Task XXII - Complete design of new injector manifolding for low temperature propellants.

Task XXIII - Initiate fabrication of new injectors.

Task XXIV - Initiate design modifications of chamber for low temperature propellants. Complete design of high temperature chamber.

FORECAST AND CONSUMPTION OF GOVERNMENT-FURNISHED PROPELLANTS

Contract NAS 3-14354

Material	Monthly Usage	Cumulative	Next Month's Requirements	Next 3 Month Requirements
LO_2 (ton)	0	0	14	112
LH_2 (lbs)	3942	7210	4600	14,200
LN_2 (ton)	49	263	150	290
GHe 10^3 (SCF), Bulk	0	99,100	12.5	25
GHe 10^3 (SCF), Cylinders	0	0	4.0	9.7

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Lewis Research Center

CONTRACT PROGRESS SCHEDULE

REPORT FOR MONTH ENDING: 25 April 1971

FORM APPROVED
BUDGET BUREAU NO 104-R0007

1. CONTRACT TITLE: Hydrogen-Oxygen APS Engines (High P_c)

2. CONTRACTOR (Name and address): Aerojet Liquid Rocket Co., P.O. Box 13222 Sacramento, California 95813

3. CONTRACT NO: NAS 3-14354

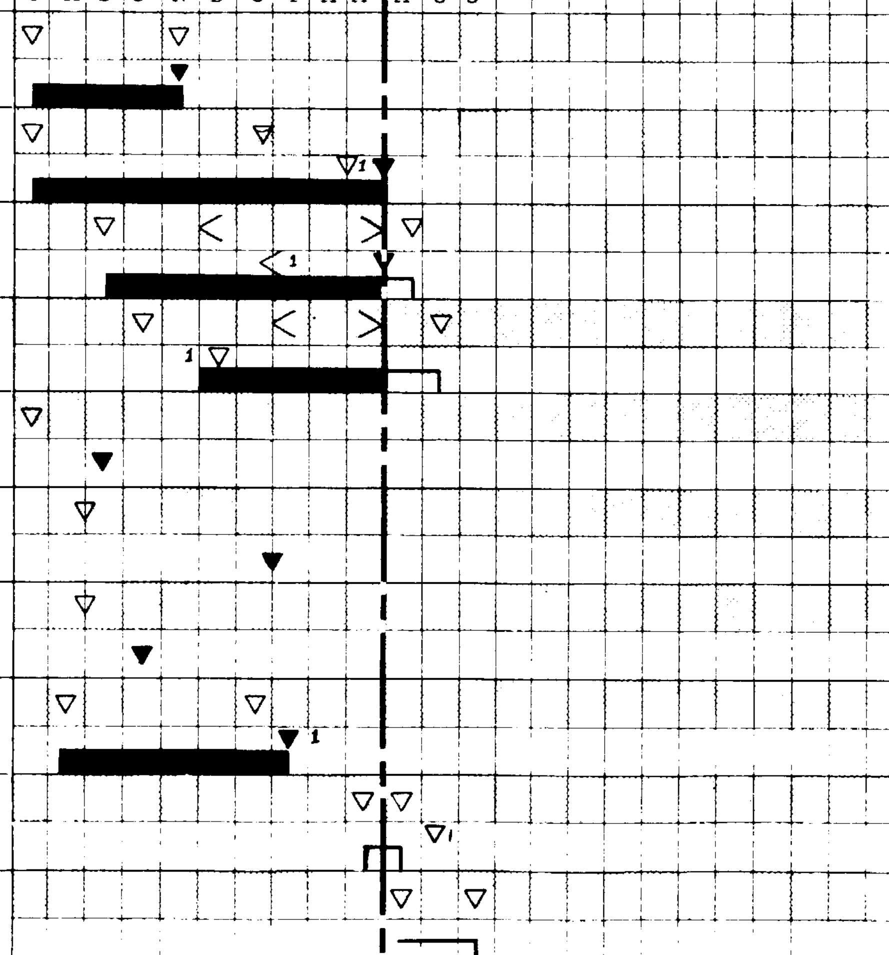
4. APPROVED (Contractor's Project Manager): L. Schoenman

PREPARATION DATE: 5-10-71

5. NASA APPROVED SCHEDULE DATE: 8-31-70

9. NASA Use Only
a. NASA CODE
b. PROJECT MGR
c. EVALUATION DATE
d. EXCEPTION CATEGORY
e. f. g.

7. 1970 1971
J A S O N D J F M A M J J



Task	6. REPORTING CATEGORY	8. TECH. OBJECTIVE % COMP.
I	Injector Analysis and Design	100
II	Injector Fabrication	100
III	Thrust Chamber Analysis and Design	100
IV	Thrust Chamber Fabrication	85
V	Ignition System Analysis and Design	100
VI	Ignition System Fabrication and Checkout	100
VII	Bipropellant Valve Preparation	100
VIII	Injector Tests	100
IX	Thrust Chamber Cooling Tests	10
X	Pulsing Tests	1

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NASA APPROVED SCHEDULE
CONTRACTOR'S WORKING SCHEDULE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Lewis Research Center

CONTRACT PROGRESS SCHEDULE

REPORT FOR MONTH ENDING	FORM APPROVED BUDGET BUREAU NO.
25 April 1971	104-R0007

1. CONTRACT TITLE
Hydrogen-Oxygen APS Engines (Low P_c)

2. CONTRACTOR (Name and address)
Aerojet Liquid Rocket Company, P.O. Box 13222
Sacramento, California

3. CONTRACT NO.
NAS 3-14354
Amendment I

4. APPROVED (Contractor's Project Manager)
A A Dau

PREPARATION DATE
5-10-71

5. NASA APPROVED SCHEDULE DATE
8-31-70

9. NASA Use Only
a. NASA CODE
b. PROJECT MGR
c. EVALUATION DATE
d. EXCEPTION CATEGORY
e. f. g.

7. 1970: A S O N D J — 1971: F M A M J J

Task	6. REPORTING CATEGORY	8. TECH. OBJECTIVE % COMP.
XI	Injector Analysis and Design	100
XII	Injector Fabrication	100
XIII	Thrust Chamber Analysis and Design	100
XIV	Thrust Chamber Fabrication	100
XV	Ignition System Analysis and Design	100
XVI	Ignition System Fabrication and Checkout	100
XVII	Bipropellant Valves Preparation	100
XVIII	Injector Tests	100
XIX	Thrust Chamber Cooling Tests	100
XX	Pulsing Tests	100

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NASA APPROVED SCHEDULE
CONTRACTOR'S WORKING SCHEDULE

X Indicates activities halted by stop work order dated 11 February 1971.

Task

XXI

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Lewis Research Center

CONTRACT PROGRESS SCHEDULE

REPORT FOR MONTH ENDING: 25 April 1971

FORM APPROVED
BUDGET BUREAU NO. 104-R0007

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PREPARATION DATE: 5-10-71

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6. REPORTING CATEGORY	7. 1970–1971: J A S O N D J F M A M J J A S O N	8. TECH. OBJECTIVE % COMP.	e.	f.	g.
Program Plan and Test Plans — High P_c		43			
Low P_c		100			
Monthly Reports		63			
Quarterly Reports		75			
Final Report Draft		0			

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CONTRACTOR'S WORKING SCHEDULE

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4. APPROVED (Contractor's Project Manager): L Schoenman

PREPARATION DATE: 5-10-71

5. NASA APPROVED SCHEDULE DATE:

9. NASA Use Only
a. NASA [illegible]
b. PROJECT [illegible]
c. EVALUATION [illegible]
d. EXCEPTION CATEGORY
e. f. g.

Task	6. REPORTING CATEGORY For Low Temperature Propellants	7. J A S O N D J F M A M J J A S O	8. TECH OBJECTIVE % COMP.
XXII	Injector Analysis & Design		
XXIII	Injector Fabrication		
XXIV	Thrust Chamber Analysis and Design		
XXV	Thrust Chamber Fabrication		
XXVI	Injector Checkout Tests		
XXVII	Cooled Chamber Tests		
XXVIII	Pulse Tests		

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CONTRACTOR'S WORKING SCHEDULE